Technical Report Documentation Page

1. REPORT No.
FHWA-CA-2153-77-10

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Correlation Of The Seismic Velocity Of Rock To The Ripping Ability Of The HD41 Tractor

5. REPORT DATE
April 1977

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Elgar Stephens

8. PERFORMING ORGANIZATION REPORT No.
19203-632153

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
F-7-102

13. TYPE OF REPORT & PERIOD COVERED
Final

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
Seismic velocities were obtained of rock where the Allis-Chalmers HD41 (now Fiat-Allis 41-B) tractor was being used, followed by observations of which rock was rippable; or in the case of already completed projects, a determination was made by interviewing inspectors, engineers, and superintendents of which rock had been rippable and which had required blasting.
The study included two types of rock on seven projects, which were the only projects to use HD41 tractors during the study time. The rock types studied were granitic and volcanic. The granitic rock consisted of fractured to massive, weathered to fresh quartz diorite, granite, and gneiss. The volcanic rocks included basalt, basaltic agglomerate, and a welded tuff. The basaltic material ranged from fresh to weathered, while the tuff was relatively fresh but ranged from intensely fractured to massive.
The rippability of rock is related to the joint spacings and rock type as well as the seismic velocity. The HD41 ripped basalt that had joint spacings of two to three feet (.6-.9 m) with occasional three to six foot (.9-1.8 m) spacings up to a velocity 7400 fps (2255 mps). Granitic rock was rippable with joint spacings of from three to fifteen feet (.9-4.6 m) up to a velocity of 5300 fps (1615 mps), but when the joint spacings were only one to three feet (.3-.9m) apart, it was rippable up to a velocity of 7600 fps (2316 mps). When the granitic material was intensely fractured (all pieces less than one foot (.3 m), most less than one half foot (.15 m)) it was rippable up to a velocity of 11,000 to 12,000 fps (3350-3800 mps). The last velocities were surface measurements made before removal of the overburden and no determination was made of the seismic velocity following removal.

17. KEYWORDS
Seismic velocity, tractor, ripper, granite, basalt, joint spacings

18. No. OF PAGES:
29

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1976-1977/77-10.pdf

20. FILE NAME
77-10.pdf

TECHNICAL REPORT STANDARD TITLE PAGE

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18. DISTRIBUTION STATEMENT
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19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	29	

DH-TL 1242 (Rev. 3-74)

16. Abstract (con't.)

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

April 1977

FHWA No. F-7-102
TL No. 632153

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

CORRELATION OF THE SEISMIC VELOCITY OF ROCK
TO THE RIPPING ABILITY OF THE HD41 TRACTOR

Study made by . . . . Geotechnical Branch

Under the Supervision of . . . . R. A. Forysth

Principal Investigator . . . . Elgar Stephens

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

EES:lrb

ACKNOWLEDGEMENTS

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Since the late 1950's, the Transportation Laboratory has been determining the depth of rippable rock on proposed construction projects at the request of the various Transportation Districts. This is done by obtaining seismic velocities of the inplace rock and relating them to the ripping ability of a particular tractor.

Transportation Laboratory rippability predictions have, for several years, been based on the use of a Caterpillar D9G as the ripper tractor. The new Allis-Chalmers HD41 (now Fiat-Allis 41B) is a larger, heavier, more powerful tractor that has the ability to rip rock that previously required blasting. The objective of this study was to determine the relationship between the seismic velocity of rock and its rippability using the new HD41 as the ripper tractor.

The rippability of rock is basically an economic consideration of what is most profitable from the viewpoint of the contractor. His interest is in moving the maximum amount of material at the least cost, including the cost of his time. What is most economical for a contractor with specific equipment at a particular site may not be so under a different set of conditions. There is a range of material hardness within which the material can be considered rippable with a specific piece of equipment. Harder material must be considered as not rippable, or rippable only with larger equipment.

A range of seismic velocities and fracture spacings also exists for each size tractor within which difficult ripping or light blasting may be required. In this range of hardness, ripping may not produce enough material, or may cause excessive wear and tear on the equipment. Under such conditions, ripping may cost more than blasting, and only be justified in the absence of drilling equipment, restrictive regulations on the use of explosives, or to complete the removal of a small remaining volume of material. Therefore, predictions of rippability have been reported on the basis of seismic velocities of in-place rock, correlated with the ripping ability of a particularly equipped tractor, driven by a competent operator. How a contractor elects to excavate material is a decision he will make on the basis of site conditions, judgement and available equipment.

The original project proposal stated some twenty sites that were representative of different rock types and conditions would be selected for testing. Sites were to be selected on the basis of rock type, hardness, fracturing, thickness of bedding (in the case of bedded sediments), and degree of weathering. Rock types to be represented included sandstone, conglomerate, limestone, granitic rock, volcanic rock, shale, silicic shale, and bedded metamorphic rocks.

At each site, a study was to be made to determine the seismic velocity of the rock. In some cases, seismic velocities would be available from studies conducted before construction began. However, it was planned to obtain additional seismic data as excavation progressed. Photographs of tractors in operation, and interviews with resident engineers, tractor operators or their supervisors at each project were also planned.

The performance of the tractor at each site was to be evaluated on the basis of such interviews and pictures, together with observations of the researcher.

Due to the limited number of test sites that were available for this study, it was found necessary to modify the proposed procedures. The actual procedures followed are described under the section: TEST PROCEDURES.

CONCLUSIONS

The following conclusions are based on the somewhat limited data available from the study.

1. The HD41 can rip granitic rock with a seismic velocity of:

   5300 fps (1615 mps), when the joint spacings are three to fifteen feet (.9 to 4.6 m) apart;

   7000 fps (2130 mps), when the joint spacings are one to two feet (.3 to .9 m) apart;

   11,000 fps (3350 mps), when the joint spacings are less than one half foot (.15 m) apart.

2. The HD41 can rip basaltic rock with a velocity of 7400 fps (2250 mps), when the joint spacings are two to three feet (.6 to .9 m) apart.

3. The HD41 appears capable of ripping rock with seismic velocities 12 to 20 percent higher than those rippable by the Caterpillar D9G.

RECOMMENDATIONS

1. Estimates of rippability using the HD41, as well as the D9G, should be provided in rippability predictions to the Transportation Districts.

2. More data should be obtained on the rippability of other materials to corroborate apparent relationships indicated by this study.

IMPLEMENTATION

Past predictions of rippability made by the Transportation Laboratory used the Caterpillar D9G as the ripper tractor standard. Based on information gained from this study, future predictions for the rippability of granitic and volcanic rock will include the HD41 as well as the D9G. Since this study did not include many of the rock types encountered in California, predictions for them will have to be based on extrapolation from types that were studied. However, there is an apparent relationship between the ripping ability of the two tractors. This relationship can be used to estimate the higher limits of the larger tractor.

The estimate of the cost of a construction project is based in part on the prediction of rippability. More realistic and up-to-date estimates of contractors' options should result in construction bids beneficial to the state.

Motion pictures of the HD41 and D9G in operation, showing some of the differences between the two tractors, will be available to Laboratory and District personnel.

TEST PROCEDURES

Due to the limited amount of construction during the study period, all construction sites where the HD41 was used were investigated, regardless of material type or geologic condition. A total of seven projects were available, representative of granitic, volcanic, and a minor amount of metamorphic rock. The rock on three sites was volcanic, and on four, granitic. One granitic site contained a small amount of metamorphic rock. The volcanic rocks represented three different conditions of hardness and fracturing. The granitic rocks represented several different conditions of weathering.

Seismic information was available prior to construction on five of the projects. Additional seismic data was obtained on three of the five. Seismic coverage was obtained following construction on two projects. Photographs of the tractor in operation were taken on only four of the projects studied as the tractor had finished on the other three before the study began.

An interview with the resident engineer and his inspector, where possible, was obtained for each project. Interviews were also obtained with contractors' superintendents (six projects), and with mechanics, engineers, and inspectors where available. The tractor operators were not readily available for interviews.

There are three different contractors represented by the seven projects. Four were done by one contractor, two by the second, and one by the third. As a result, some of the same equipment and personnel were represented on more than one project. Three of the first contractor's projects were under the same superintendent, who usually had the same ripper tractors and operators. The two projects by the second contractor had different superintendents but the same tractor and same operator.

Many hours were spent in the field observing the tractors in operation. These observations were supplemented by motion pictures which were studied at the Laboratory.

Many of the construction people interviewed in the field emphasized the importance of the "availability" of the HD41 tractor, which can be defined as the percent of time that it is available to work during its regular shift. Repairs and maintenance performed during the work shift would result in a lower availability. Most contractors interviewed considered the minimum acceptable availability to be 90 percent. The availability of the HD41 was considered to be good on six of the seven projects studied and poor on one.. A major factor in the single project considered to have "poor" HD41 availability was the lack of experienced operators.

In the words of the superintendent of Company A, a good operator will result in good availability of the tractor and visa versa. This opinion is also held by officials of Company B, where only certain operators are assigned to the HD41. If that operator is ill or otherwise not available, the tractor is not used until his return. These company representatives believe that an operator who does not fully understand the tremendous power of this tractor will operate in such a way as to cause damage to the machine. Observations during the course of this study corroborate these opinions on the necessary qualifications for operators.

To appreciate the size of the HD41, it is necessary to compare it to the Caterpillar D9G. The latter has a working weight of 100,000 pounds (45,400 Kg) and a 385 horsepower engine, whereas the HD41 has a working weight of 155,000 pounds (68,000 Kg) and a 524 horsepower engine. The relative sizes of the two tractors are shown in Figures 1 and 2.

Figure 1. Front view of the two tractors, HD41 on the left, D9G on the right.

Figure 2. Side view of the two tractors. HD41 with double tooth ripper on the left, D9G with single tooth ripper on the right.

TEST SITES

Highway District 2, Tehama County, Route 36

This project had been completed before the study began, but detailed information was available on the methods of excavation. Information was obtained from the resident engineer, district materials engineer, the contractor's superintendent, and the subcontractor who had done drilling on the site.

The material was volcanic, ranging from clayey colluvium to relatively unweathered basalt and andesite, and from ashy pumaceous material through cemented agglomerate. Seismic velocities were obtained after completion of the construction, involving much extrapolation and interpolation. However, there was basic agreement between the velocities obtained after construction and those obtained by the contractor before construction began.

Two ripper tractors were used - an Allis-Chalmers HD41, and a Caterpillar D9G. Most of the hard ripping was done by the HD41, which made 600-1000 cubic yards (459-765 cubic meters) per hour in all but the hardest material. This tractor worked two shifts, and had little down time. In the project superintendent's opinion, the two tractors must produce a minimum of from 300 to 400 cubic yards (229 to 306 cubic meters) per hour if ripping is to be more economical than blasting. Depending on the volume of material needed to supply scrapers, the amount remaining to be excavated, availability of drills, and preferences of the contractor, blasting will start when production is 150 to 200 cubic yards (115 to 153 cubic meters) per hour from the D9G, and approximately 250 cubic yards (191 cubic meters) per hour from the HD41. The D9G production dropped to this level, but the HD41 continued producing at a rate such that no blasting was necessary. A small knob in a borrow area was not rippable by the HD41. A seismic velocity of 12,100 fps (3688 mps) was recorded for this knob. A few widely spaced, tightly closed joints were noted. Although there were few joints in the cemented agglomerate that was rippable by the HD41, but not by the D9G, there were many softer zones or lenses that provided an entry for the HD41 ripper tooth.

The total amount of excavation and borrow was 1,154,700 cubic yards (882,830 cubic meters). Three percent had a velocity over 6150 fps (1850 mps) and would have been considered blasting rock under the previous classification. Another four percent had a velocity between 5000 and 5800 fps (1524 and 1770 mps) and would have been classified as difficult ripping to light blasting.

Highway District 7, Ventura County, Route 101

Although this project was partially constructed by the time the study began, seismic velocities in the area were available as part of the design study. On the basis of the seismic study and a geologic reconnaisance, the material was determined to require blasting, and presplitting was recommended. The rock consisted of hard dense basalt, hard broken basalt, relatively fresh to well-weathered basaltic agglomerate, and fresh to weathered tuff.

The successful bidder had already completed at least one project on which the HD41 had ripped rock thought to require blasting.

The contractor began excavation using the HD41 as the ripper tractor, and, on the basis of his early success, requested the presplitting requirement be dropped. Although the request was granted, only a portion of this job was ripped effectively by the HD41. This early success was on the westbound offramp, which included large amounts of material not rippable by a D9G, but which was ripped by the HD41. It had velocities that ranged from 4500 to 7650 fps, (1320 to 2330 mps) with most of the material having a velocity less than 7000 fps (2130 mps). The D9G was unable to rip material with a velocity of over approximately 6000 fps (1830 mps). The HD41 ripped the 7000 fps (2130 mps) material with moderate difficulty, and the 7650 fps (2330 mps) material with difficulty and only marginal production.

In the main cut area, much of the material was either soft enough to be ripped by a D9G, or was so hard that it was not rippable by an HD41. The method then used was a combination of light blasting and heavy ripping by the HD41 (see Figure 3). The combination produced rock fragments with a maximum diameter of two to three feet (.6 to .9 m). The material had seismic velocities of from 4500 to 13,900 fps (1370 to 4230 mps).

All of the material with a velocity greater than 7400 fps (2250 mps) was blasted, using a powder factor of approximately one pound per cubic yard (.6 Kg per cubic meter). Material with velocities up to approximately 8700 fps (2650 mps) was first blasted, then ripped. Material with a velocity of 12,000 to 14,000 fps (3650 to 4360 mps) was removed entirely by blasting. This operation was a combination of production type blasting away from the backslope, and controlled blasting and ripping near the backslope. The holes nearest the face were drilled vertically on four foot (1.2 m) centers to a depth of ten feet (3 m) with the bottom of the hole then being two feet (.6 m) from the position of the finished slope. The HD41 could then rip and blade to finished slope without materially damaging the slope.

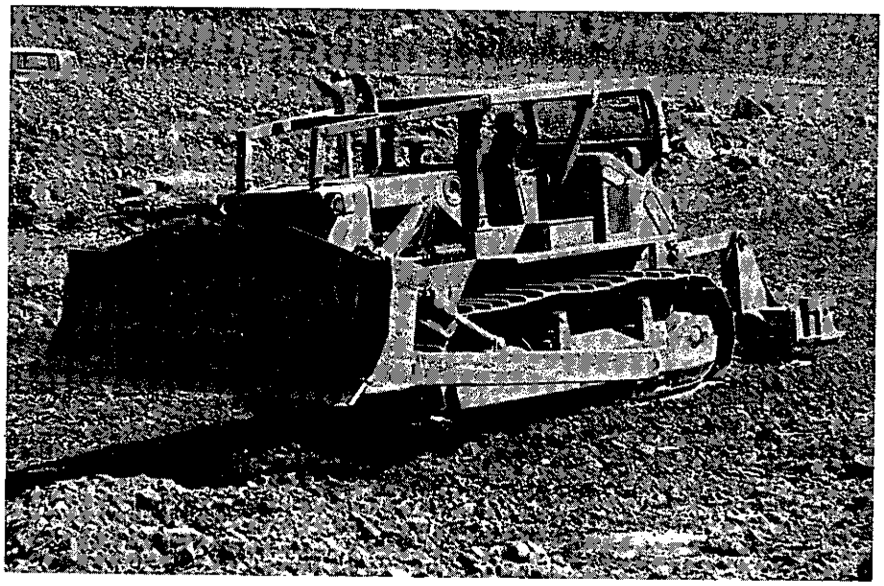

Figure 3. HD41 ripping basaltic rock in the main bowl area of the cut, 07-Ven-101.

Highway District 8, Riverside County, Route 60

This project was observed throughout the construction period. Photographs and motion pictures were obtained of the HD41 and D9G in operation. The resident engineer, grading inspector, contractor's superintendent, and the company mechanic were interviewed. A seismic survey had been conducted during the design phase and additional seismic data were obtained during construction.

The material on this job was principally a quartz diorite that ranged from disintegrated to slightly weathered, and had seismic velocities ranging from 1700 to 9200 fps (518 to 2800 mps). Joint spacings ranged from two to fifteen feet (.6 to 4.5 m) with an average of four to five feet (1.2 to 1.5 m) (see Figures 4, 5, and 6). There was some metamorphic rock, probably roof pendants, consisting of schists and quartzite. There were also several faults and numerous pegmatite and aplite dikes.

Where the rock was very hard, it was blasted and removed using loaders and rock trucks. This operation required a D9G with blade, the loader, and several rock trucks and could remove approximately 5000 cubic yards (3820 cubic meters) per shift.

Where the HD41 could rip, the rock was removed using scrapers. The HD41 was the primary ripper, and was equipped with a single five foot (1.5 meter) ripper tooth. It was assisted by a D9G with a single four foot (1.2 meter) tooth and a D9G with two-three foot (.9 meter) teeth and a slope board. Other equipment used included three D9G pusher tractors and six twin engine Caterpillar scrapers (see Figures 7, 8, and 9). This operation moved 13,000 to 14,000 cubic yards (9940 to 10700 cubic meters) per shift. Based on several hours observation of the ripper tractors on

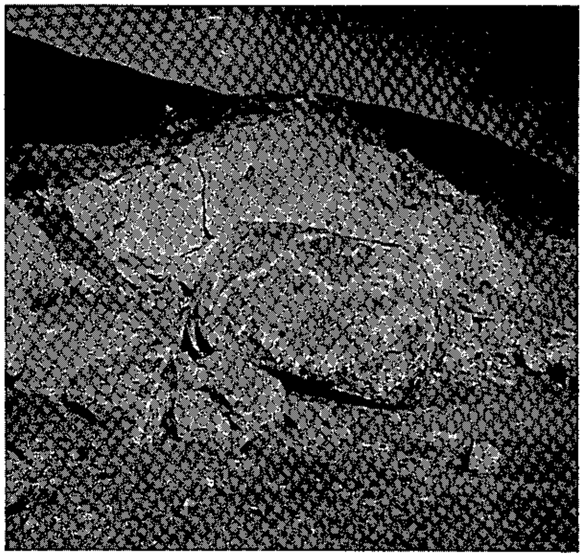

Figure 4. Large granitic boulders and an unweathered block at Sta 330, 08-Riv-60.

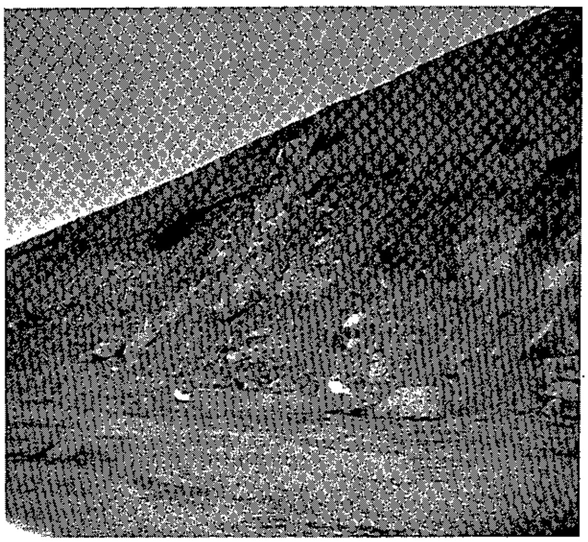

Figure 5. Granitic cut near Sta 331 showing hard zones which required blasting, 08-Riv-60.

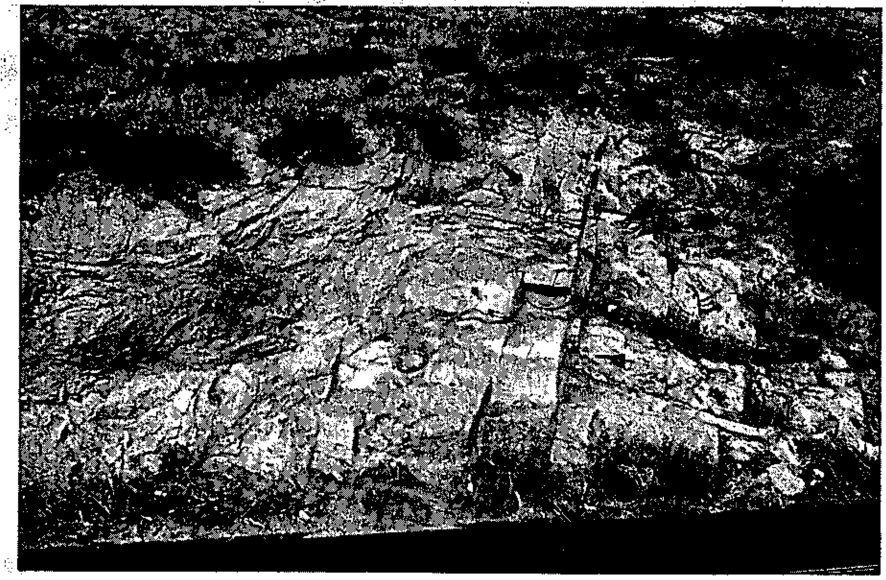

Figure 6. Cut along existing roadway showing jointing and weathering of granitic rock near Sta 327, 08-Riv-60.

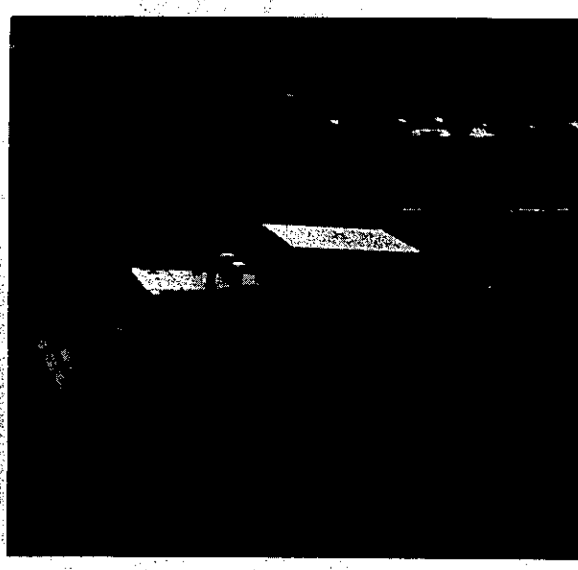

Figure 7. HD41 Ripping with a single five foot (1.5 m) Ripper tooth in granitic rock near Sta 330, 08-Riv-60.

Figure 8. D9G Ripping granitic rock with a single four foot (1.2 m) tooth near Sta 328. Note that tractor is on "tiptoe", and tooth is not fully in ground, 08-Riv-60.

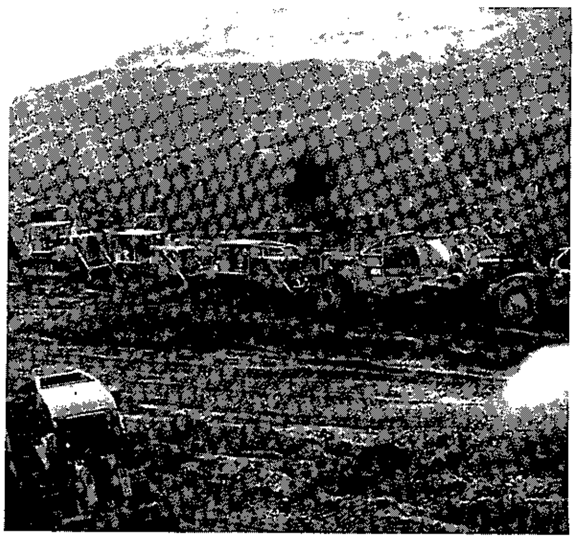

Figure 9. Scraper spread in operation. Three D9G pusher tractors are loading scraper. D9G, equipped with two-three foot (.9m) teeth and a slopeboard, operating in foreground, 08-Riv-60.

several different days, the HD41 probably produced 2/3 of the material that was ripped, amounting to something over 1100 cubic yards (840 cubic meters) per hour. When the material became so competent that this volume of material was not available to the scrapers, the contractor began light blasting to increase the production rate. This type of light blasting used a hole spacing of 7 by 7 feet (2.1 by 2.1 meters) and a powder factor of from 1/3 to 1/2 pound per cubic yard (.2 to .3 Kg per cubic meter). The material that was being shot in this way had an in-place seismic velocity of approximately 5300 fps (1615 mps). Joints were tightly closed and not visible prior to blasting. However, the material tended to separate on joint planes when it was heaved. The HD41 then ripped along parallel passes five feet (1.5 m) apart with the five foot (1.5 m) tooth at full penetration. This combination of tearing by the ripper tooth and the crushing action of the treads produced a finely broken material resembling a coarse sand. There were some remnant round hard knobs resulting from differential weathering that were not rippable. These were shot using a powder factor of from 3/4 to 1 1/2 pounds per cubic yard (.44 to .89 Kg per cubic meter).

It was observed on this project, and pointed out by construction personnel on others that operator competence is an important factor in comparing the performance of the HD41 and D9G tractors. Here, the HD41 operator was obviously more effective. A comparison of the output of these two tractors is therefore biased by this difference in operator competence.

On this project the availability of the HD41 was about equal to that of the D9G.

The HD41 ripped rock with a seismic velocity 500 to 1000 fps (150 to 300 mps) higher than that ripped by the D9G, while slipping less, traveling faster, and penetrating 100 to 200 percent deeper.

Highway District 7, Los Angeles County, Route 2

Construction was partially completed by the time this study was begun. A seismic survey had been conducted previously for design information. Additional seismic information was obtained from a study done by a consultant for the contractor, and from a study by the Transportation Laboratory after the completion of excavation.

Information was also obtained from the resident engineer, the grading inspector, and the contractor's superintendent.

The material on this project was a quartz diorite and gneissic quartz diorite with complex and persistent jointing. Jointing was probably the most important single factor with respect to the rippability of the rock. The condition of the rock varied from fairly fresh to quite weathered. Joint and fracture spacings ranged from three inches to one foot (7.6 to 30 cm) in many areas. Fracture spacings of two to three feet (.6 to .9 m) were the average in other areas, with some spacings of up to four feet (1.2 m). The depth of weathering had been influenced by the jointing so that the more closely jointed rock was the more weathered and had wider fracture openings. At depths of from 50 to 100 feet (15 to 30 m), the material was still relatively fresh even in areas of very broken material. In this situation the joints were still very tight and did not provide an easy entry point for the ripper tooth. There was also a velocity increase when these joints were tightly closed.

The velocity of the rippable material varied with the spacing of the fractures, width of the openings, and hardness of the individual pieces. A relatively fresh gneiss, with tight joints spaced one to four feet (.3 to 1.2 m) apart, was rippable to a velocity of about 6000 fps (1830 mps). Highly jointed rock with spacings of three inches to two feet (7.6 to 61 cm) was rippable to a velocity of 7400 fps (2250 mps). Some relatively unweathered but highly fractured material with tightly closed fractures spaced less than six inches (15 cm) apart and a velocity of 9400 fps (2860 mps) was rippable with difficulty. The ripper tooth did not enter the fractures, however, the weight of the tractor concentrated on the tooth caused the material to fail. Due to the highly abrasive nature of this material and the uncertainty of ripping large volumes for a scraper spread, light blasting was done throughout most such material.

The HD41's were the primary tractors and used for all heavy ripping and push loading on this project.

Highway District 11, San Diego County, Route 15

This project was started after the research study had begun, and was observed throughout the construction period. Information was obtained from a seismic investigation which had been made for design purposes, and interviews with the resident engineer, grading inspector, construction superintendent, and project engineer.

The material was a relatively massive granitic rock with a minor amount of metamorphic rock in one area.

Much of this project used an HD41 as the primary ripper tractor.

The large cut on the north end of the project was excavated with a D9G ripper tractor. Material which the D9G could not rip was blasted.

For most of the project, the ripping assignments were shared by an HD41 and one or more D9G tractors. The D9G's were able to rip granitic rock with a seismic velocity of about 5000 fps (1520 mps) and joint spacings of from one to four feet (.3 to 1.2 m). The HD41 ripped granitic rock with a seismic velocity of 5650 fps (1722 mps) with moderate difficulty when it had joint spacings of from six inches to two feet (15 to 61 cm). It ripped granitic rock with a seismic velocity of 7600 fps (2316 mps) with joint spacings of one to three feet (.3 to .9 m) with extreme difficulty. Material with a velocity of 8000 fps (2440 mps) or greater was blasted. The HD41 also ripped hornfels with a seismic velocity of 5250 fps (1600 mps) and joint spacings of six inches to two feet (15 to 61 cm) with moderate difficulty.

Highway District 9, Mono County, Route 395

This project was completed before the study began. Rippability information was assembled from interviews with the resident engineer, his assistant, and one of the inspectors. Seismic studies performed by two consultants for the contractor were available for evaluation. Additional seismic work was done by the Transportation Laboratory after the project was completed.

The material is a welded tuff. While there was some variation in closeness of joints and degree of weathering, the material was remarkably uniform throughout the project.

Several ripper tractors were used on the project. The work was started using D9G's; one with a single tooth and two or more with double teeth. The DH41 was later brought in to rip using one to three teeth. The principal area of use was where material could be reduced to the proper size for scrapers by two or three passes of the D9G, or by one pass of the HD41. For most of the more difficult ripping, the D9G used a single tooth while the HD41 used two teeth. The seismic velocities ranged from 5000 to 5900 fps (1524 to 1800 mps), a range that would ordinarily be classed as difficult ripping for the D9G. The performance of the tractor was in agreement with this classification. This material had joint spacings of from one to five feet (.3 to 1.5 m) and was ripped with only moderate difficulty by the HD41. No material hard enough to require blasting was encountered.

Highway District 8, San Bernardino County, Route 40

This project had been completed before the study began. A seismic study had been made for design purposes and there was a final review of the project after excavation. At that time interviews were obtained with the resident engineer and the contractor's superintendent. The superintendent also provided a copy of the seismic study done for them by a consultant. The project was inspected to determine which materials had been blasted and which had been ripped. The resident engineer, contractor's superintendent and this researcher also discussed the effectiveness of the then new Allis-Chalmers tractors (HD41).

The material was granitic rock, blocky and massive on the west end, broken and shattered towards the east end.

The seismic study done by the Transportation Laboratory indicated that based on the use of a D9G as the ripper tractor, about 340,000 cubic yards (260,000 cubic meters) would require blasting. The amount of material actually blasted was about 15,000 cubic yards (11500 cubic meters). The superintendent stated that they had tried ripping with the D9G, but were not successful. He then brought in two HD41 tractors, which were successful. He described the rock on the east end of the project as being well shattered. Although individual pieces were very hard, joint width was sufficient to permit penetration of the ripper tooth into the fractures. He indicated, on the ground and on cross sections, where the material had been blasted or ripped.

The rock on the west end of the project was less fractured. It was rippable up to a velocity of approximately 6100 fps (1860 mps), above which local blasting of hard spots was usually necessary. In the central area, relatively massive material with a velocity of 6550 fps (1996 mps) was all blasted.

The fracturing of the granitic rock on the east end was much greater. However, seismic velocities measured from the ground surface in the area of the shattered rock were 11,000 to 12,500 fps (3350 to 3800 mps). The contractor stated this material had "hard" and "soft" zones. The soft zones were ripped with only moderate difficulty by the HD41. The hard zones were ripped with difficulty and required local light blasting. One section near the bottom of the south roadbed required regular blasting to remove approximately ten to twenty feet (3 to 6 meters) of rock along 200 feet (61 meters) of roadway.

GENERAL OBSERVATIONS

Observations made during the study indicate the rippability of rock with any ripper tractor is related to joint spacing, seismic velocity, and rock type. Table 1 summarizes the rippability of the rock types studied, using the HD41 as the ripper tractor. The table relates the joint spacings, seismic velocities, and rock types to the rippability.

The HD41 can exert more force, and will rip tougher and harder materials than the D9G. However, it can rip only what the tooth can penetrate. Fractures are the usual weakness that allows the tooth to penetrate. Where there are no fractures, the granitic rock seems to be too tough for penetration until weathering has progressed to a degree such that the feldspars can be crushed by the tooth. This point for the HD41 appears to be approximately 5500 fps (1670 mps) for massive rock.

Spacing and openness of fractures also has a direct effect on the seismic velocity. Highly fractured rock tends to have a lower velocity than an equally weathered but less fractured material. A fractured rock with a relatively high velocity tends to have closed fractures and individual pieces that are very hard. The seismic velocities of 11,000 to 12,500 fps (3350 to 3800 mps) in the shattered granitic material along Highway 40 represents material that is completely broken, but only slightly weathered. The fractures are tightly closed and thus have little effect on the seismic wave.

A broken material with an in-place seismic velocity of 11,000 fps (3350 mps) underlying a 40 to 50 foot (12.2 to 15.2 m) thick overburden would not be expected to be rippable. It is possible that the fractures open as the overburden is removed. This inelastic deformation would result in a decrease in the seismic wave velocity, as well as permitting the material to be more easily excavated. Velocities were not obtained to determine if such deformation was taking place at any of the sites investigated as part of this study.

It appears that for the two rock types studied, the HD41 can rip material with seismic velocities on the order of 12 to 20 percent higher than what is rippable by a D9G. These findings will be considered in future predictions of the rippability of granitic or volcanic rock. Predictions for other rock types will have to be estimated on the basis of a conservative interpretation of this data until additional evidence has been collected.

TABLE 1

Maximum Rippable Velocity Related to Rock Type and Joint Spacings on the Studied Projects

Velocity		Rock Type	Joint Spacings		Project
fps	(mps)		ft.	(m)	
5,300	(1615)	Granitic	3-15	(.9-4.6)	08-Riv-60
6,000	(1829)	"	1-4	(.3-1.2)	07-LA-2
6,100	(1859)	"	2-3	(.6-.9)	08-SBd-40
7,000	(2134)	"	1-2	(.3-.6)	07-LA-2
7,600	(2317)	"	1-3	(.3-.9)	11-SD-15
11,000	(3353)	"	<1/2	(<.15)	08-SBd-40
7,400	(2255)	Basalt			02-Teh-36
7,400	(2255)	"	2-3	(.6-.9)	07-Ven-101
5,900*	(1799*)	Welded Tuff	1-5	(.3-1.5)	09-Mno-395

*Highest velocity for material on the job - only moderately difficult ripping.